AN APPRAISAL OF DIFFERENTIAL TEMPERATURE ADVECTION AND MOISTURE AS A FORECASTER OF HEAVY RAINFALL

GEORGE A. LOTT

Hydrologic Services Division, U. S. Weather Bureau,[1] Washington, D. C

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ABSTRACT

A series of 78 daily forecasts using differential temperature advection and moisture as a predictor of heavy rainfall is verified. The evaluation indicates that the method has some skill in detecting winter days on which to expect heavy rain, and where it will occur. A breakdown by amounts shows that the heavier the rainfall, the greater the probability of its occurrence being forecast and the greater the accuracy in the placement of the rainfall center.

1. INTRODUCTION

The problem of the prediction of heavy precipitation is one of the most difficult in the science of meteorology. It is at the same time one of vital importance for river forecasting and flood control operations. As a part of its function, the Hydrometeorological Section of the Division of Hydrologic Services of the Weather Bureau has made several approaches to the problem, one of which will be appraised here. This paper reports the results of a test of Gilman's [1] concept of differential temperature advection as a cause of vertical motions in the atmosphere leading to heavy rainfall if sufficient moisture is present.

2. THE TEST

During the period from October 26, 1953, to March 1, 1954, inclusive, a series of 78 daily forecasts of heavy rainfall was made in the Hydrometeorological Section. The forecasts were made Monday through Friday of each week except for the period December 24, 1953, to January 3, 1954.

A detailed account of the method used in arriving at the forecast has been presented by Appleby [2]. Briefly, the method consists of advecting the isotherms and dewpoint lines on the 850-mb. chart by means of forecast air trajectories. A grid is then placed over the chart and the present and future temperatures read off. Temperature changes are computed at the grid points. The Laplacian of these forecast changes is calculated and is defined as the differential temperature advection. When areas of forecast warm differential temperature advection and high moisture overlap, heavy rain is expected.

All of the forecasts were made from the 0300 GMT 850-mb. chart for the 6-hour period, 1200–1800 GMT, the same day. The 0630 GMT surface map and the 30-hour prognostic surface map (made from 0630 GMT data), together with a certain amount of judgment, were used to forecast the movement and to some extent the change in shape of the 850-mb. features. These 0630 GMT data were the latest used.

Isolines of forecast differential advection of $-4°$ C./6 hour/° latitude/° latitude were drawn. This value was chosen on the basis of some preliminary forecasts during the early fall of 1953. Minus 4° was selected at the beginning of this test and maintained throughout the series. It may be noted however, that a value of $-2°$ C. was used by Appleby [2]. Forecast values of moisture of 10° C. and 12° C. dewpoint at the 850-mb. level were both used and the results summarized.

3. ERRORS

Errors that may enter into the calculation of the forecast parameters can be classed as follows:

(1) Errors in the prognosis of: (a) frontal positions, (b) change in shape of systems and (c) change in intensity of systems. Generally, errors of type (a) are not as serious as might be supposed. This is because the winds are used to move the isotherms and small errors in the movements of the system affect only a slight displacement of the forecast heavy rain area and usually not its existence. The errors of type (b) and (c) may be very serious. It is here that the skill of the forecaster can come into play most efficaciously.

(2) Errors in the short-cut trajectory method of moving the isotherms. This type is rather hard to assess, but some preliminary comparisons with more laborious methods of trajection show comparable results.

(3) Errors in differential advection due to non-advective temperature changes. This error was most pernicious in regard to the downwind change in the temperature field aloft caused by the formation of a rainfall area after the

[1] In cooperation with Corps of Engineers, Department of Army.

time of the upper air observations from which the forecast is made.

(4) Errors due to approximations used in the computation of the differential advection. The differential advection is computed as an average over a 6-hour period. While this is reasonable in view of the duration of heavy rains (not duration at a given point on the earth's surface), some heavy rain cases of very short duration may be missed by the averaging process.

(5) Errors in reported upper air data. This source of error is considered small.

(6) Errors in analysis of the upper air data. For the most part this error is small except for a spatial inadequacy in moisture observations. In a few situations large errors could result unless judgment is exercised in analyzing the moisture field by taking surface data into consideration.

4. VERIFICATION

It was decided that there was not enough congruity between forecast and observed areas to employ elaborate areal verification techniques for judging the results of the method. Accordingly, a simple measure, the distance between the observed and forecast areas, was used and the results summarized in a number of contingency tables (fig. 1). To show how much better than chance the forecasts were, a skill score was computed for each test using the marginal totals as climatology. The skill score measures the scheme's ability to predict the occurrence or nonoccurrence of a precipitation area of a specified intensity (or the number of precipitation areas of a specified intensity more than 100 miles apart at their periphery) within the United States east of the Rockies, except the Florida peninsula, for a given 6-hour period.

While in general the shapes of the forecast areas of differential temperature advection and the associated rain areas were not similar, there is some reason to believe that a more careful and detailed analysis would improve the correspondence. In a test of three historical situations (not part of this series) made with great care on a large scale map the correspondence of position and shape of the forecast and observed rain areas was very close. Two of these three historical cases were discussed by Appleby [2].

For rainfall verification all recording rain gage data appearing in climatological data for the United States east of the Rocky Mountains were examined. For each forecast day all significant rainfall was plotted for the period 1200–1800 GMT and isohyets drawn for values of intervals of ¼ inch.

On each day that the forecast was made it was noted whether the parameters congruently reached the following "critical" values: $\geq 10°$ C. and $\geq 12°$ C. 850-mb. dewpoint together with $-4°$ C. differential advection. If no area was formed by the overlapping of the above values the forecast was for no heavy rainfall (heavy rainfall being defined as 1 in./6 hr. and .75 in./6 hr.) in the United States east of the Rocky Mountains (except the Florida peninsula). A heavy rain "hit" was recorded when a forecast area and an observed area (of specified magnitude) occured within the United States east of the Rockies, except the Florida peninsula, no matter what the distance between them. This was done in order to avoid the use of an arbitrary criterion for success or failure of a forecast. In each case the distance between them was measured from center to center. A summary of the distances is presented in histogram form with each contingency table.

In cases where multiple rain or forecast areas were encountered, the following rules were observed: (1) When the edges of two observed heavy rain areas were within 100 miles of each other at their closest, they were counted as a single combined area. (2) Two heavy rain forecast areas were treated as two separate areas regardless of the distance between them. (3) If two heavy rain areas were forecast and two observed, each forecast area was paired with the nearer heavy rain area and this distance was recorded. (4) If one rain area was observed but two heavy rain areas were forecast, the nearer heavy rain area was paired with the forecast area and the other area was counted as a "miss". The same rule was followed with two observed heavy rain areas and one forecast area.

The verification of rainfall areas and/or forecasts near the coastline presented a difficulty. It was decided that for consistency the forecast heavy rain areas would be ignored if they occurred entirely off the coast but if they occurred partly on and partly off the coast to use only that part over land. In this way the observed and forecast areas are treated equally, although a slight bias toward reducing the verification score results. This was deemed fairer than introducing a favorable bias of unknown magnitude.

In these contingency tables the no-heavy-rain-forecast, none-observed box has only one observation per day, while the other boxes on a few days contain more than one per day. This bias was not thought to be large enough to seriously affect the judgment of the method.

5. EVALUATION

A summary of results attained by the method in the daily series is given in figure 1 and table 1. It would appear from the contingency tables (fig. 1) that a positive, though not high, skill above chance in selecting those winter days on which to expect heavy rain, was exhibited in all the tests. Test No. 1 (differential temperature advection $\leq -4°$ C.; dewpoint $\geq 10°$ C.; 6-hour rainfall ≥ 1.00 inch), which forecast heavy rain 37 times when heavy rain was observed 33, showed the highest skill score as well as the best balance. These values of the parameters should be preferred over the others when the method is used.

The median distance that was missed varied from 140 to 165 miles and probably does not represent a significant difference among the tests.

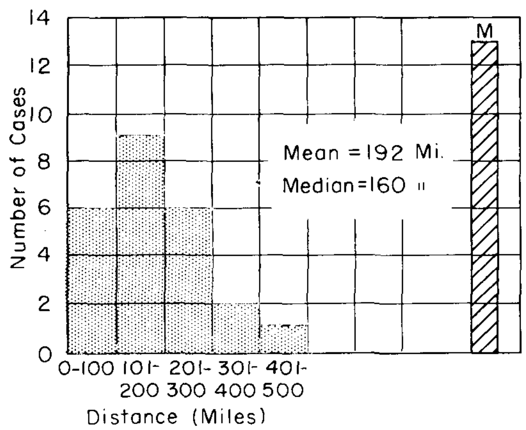
The skill scores also show the method works considerably better at forecasting rains over 1.00 inch than with rains over 0.75 inch. A further extension of this effect

Test No. 1

Forecast differential temp. advection, 850 mb. ≤ -4°C.
Forecast dew point at 850 mb. ≥ 10°C.
6-hour rainfall (1200-1800 GMT) ≥ 1.00 in.

		Forecast Heavy rain	Forecast No heavy rain	Total
Observed	Heavy rain	24	9	33
	No heavy rain	13	50	63
	Total	37	59	96

SS = .51
P_1 = 65
P_2 = 73

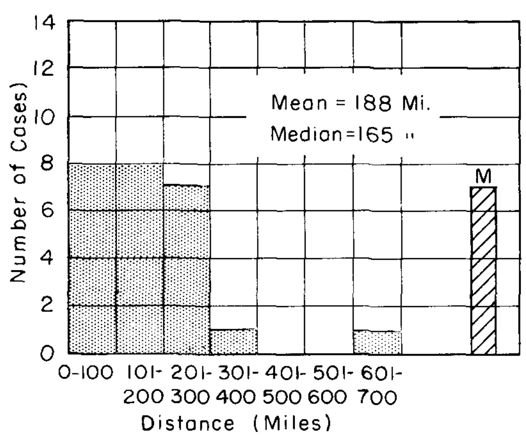


Test No. 2

Forecast differential temp. advection, 850 mb. ≤ -4°C.
Forecast dew point at 850 mb. ≥ 12°C.
6-hour rainfall (1200-1800 GMT) ≥ 1.00 in.

		Forecast Heavy rain	Forecast No heavy rain	Total
Observed	Heavy rain	19	14	33
	No heavy rain	7	52	59
	Total	26	66	92

SS = .48
P_1 = 73
P_2 = 58

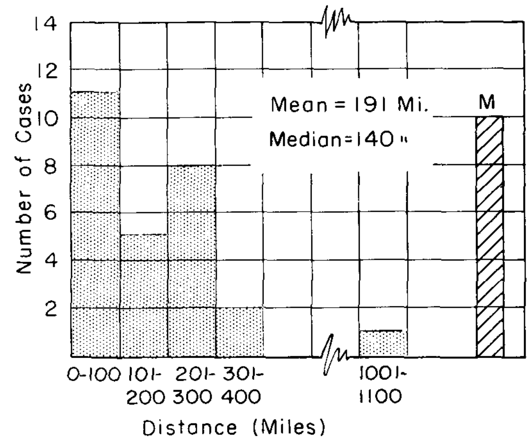


Test No. 3

Forecast differential temp. advection, 850 mb. ≤ -4°C.
Forecast dew point at 850 mb. ≥ 10°C.
6-hour rainfall (1200-1800 GMT) ≥ 0.75 in.

		Forecast Heavy rain	Forecast No heavy rain	Total
Observed	Heavy rain	27	20	47
	No heavy rain	10	47	57
	Total	37	67	104

SS = .41
P_1 = 73
P_2 = 57



Test No. 4

Forecast differential temp. advection, 850 mb. ≤ -4°C.
Forecast dew point at 850 mb. ≥ 12°C.
6-hour rainfall (1200-1800 GMT) ≥ 0.75 in.

		Forecast Heavy rain	Forecast No heavy rain	Total
Observed	Heavy rain	21	26	47
	No heavy rain	5	48	53
	Total	26	74	100

SS = .36
P_1 = 81
P_2 = 45

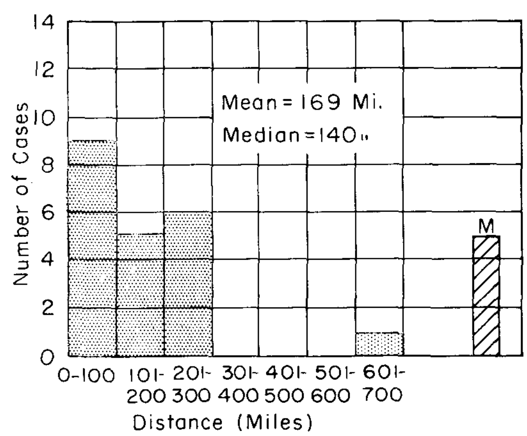


FIGURE 1.—Contingency tables for heavy rain forecasts and histograms showing distances in miles between forecast and observed heavy rain areas (shaded) and number of cases when heavy rain was forecast but not observed (M, hatched). SS=skill score, P_1=percentage of heavy rain forecast that verified, P_2=percentage of observed heavy rainfalls that were forecast.

TABLE 1.—*Cases of observed rainfall≥1 inch in tests No. 1 and No. 2, categorized by rainfall intensity and mean distance between forecast and observed rain centers. P_2=percentage correct*

	Test No. 1 850-mb. dew point≥10° C.			Test No. 2 850-mb. dew point≥12° C.		
Observed \ Forecast	Heavy rain	No heavy rain	Total	Heavy rain	No heavy rain	Total
Heavy rain	24	9	33	19	14	33
Intensity Breakdown (cases)						
≥3 in.	2	0	2	2	0	2
2–3	8	1	9	6	3	9
≥2	10	1	11 (P_2=91)	8	3	11 (P_2=73)
1–2	14	8	22 (P_2=57)	11	11	22 (P_2=50)
Mean Distance Breakdown (mi.)						
Heavy rain	192	(24 cases)		188	(19 cases)	
≥2 in.	162	(10 cases)		122	(8 cases)	
1–2	213	(14 cases)		236	(11 cases)	

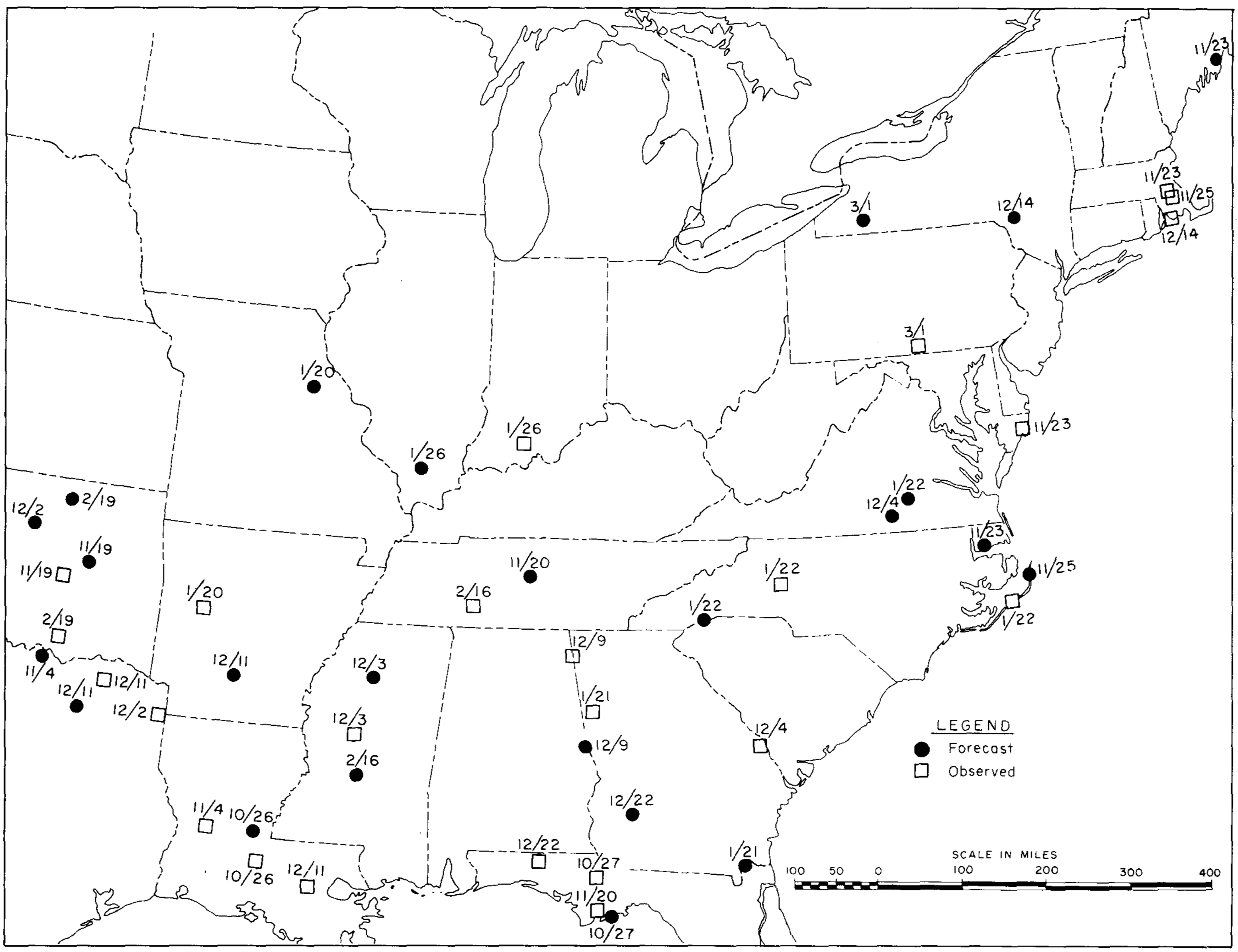


FIGURE 2.—Dates and locations of centers of successful heavy rain forecasts and observed heavy rains, test no. 1 only.

is seen in the breakdown of rains over 1.00 inch. The highest 6-hour amount recorded during the test was 3.10 inches on December 3, 1953. There were 2 cases with observed amounts above 3 inches, both of which were forecast. Table 1 shows a breakdown of the observed heavy rain cases into rainfall intensity categories.

It would appear from this breakdown that the heavier the rainfall, the more skill the method has in being able to forecast it. For example, test no. 1 (6-hour rainfall$\geq$ 1.00 inch) P_2 has a value of 73 percent. This measure is 57 percent for rains between 1 and 2 inches but becomes 91 percent for rains over 2 inches. The average distance missed also is less. A similar trend was also found in test no. 2.

No relationship was found between the differential advection alone as measured by the present procedure and the 1–2 inch rains as differentiated from those over 2 inches.

Another way to demonstrate the skill possessed by the method was to plot the scatter of observed heavy rain "hits" (test no. 1 only). It can be seen (fig. 2) that they are fairly well distributed from the Texas-Oklahoma region to New England. A mechanical forecast of heavy rainfall was then made using the centroid of the observed heavy rainfall centers. A histogram of the resulting distances missed (fig. 3) may be compared directly to the distances missed of test no. 1 (fig. 1). It can be noted that a marked decrease is attributable to the method.

6. SUMMARY

The method reveals a certain skill in detecting those winter days on which to expect heavy rain and where it will occur. The heavier the rainfall, the greater the probability of its being picked out and the greater the accuracy in the placement of its center. It must be the decision of the prospective user, however, whether the manpower required to make the forecast is balanced by the knowledge gained.

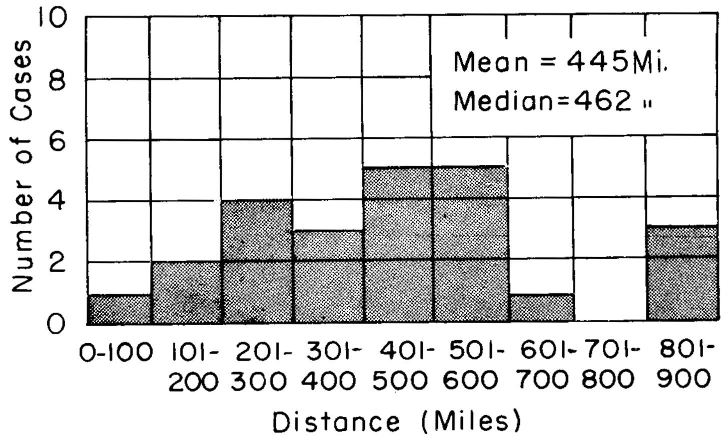


FIGURE 3.—Histogram of distances between centroid of observed heavy rains (used as a forecast) and locations of observed heavy rain.

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REFERENCES

1. C. S. Gilman, "Expansion of the Thermal Theory of Pressure Changes," Sc. D. Thesis, Massachusetts Institute of Technology, 1949 (unpublished).
2. J. F. Appleby, "Trajectory Method of Making Short-Range Forecasts of Differential Temperature Advection, Instability, and Moisture," *Monthly Weather Review*, vol. 82, No. 11, November 1954, pp. 320–334.